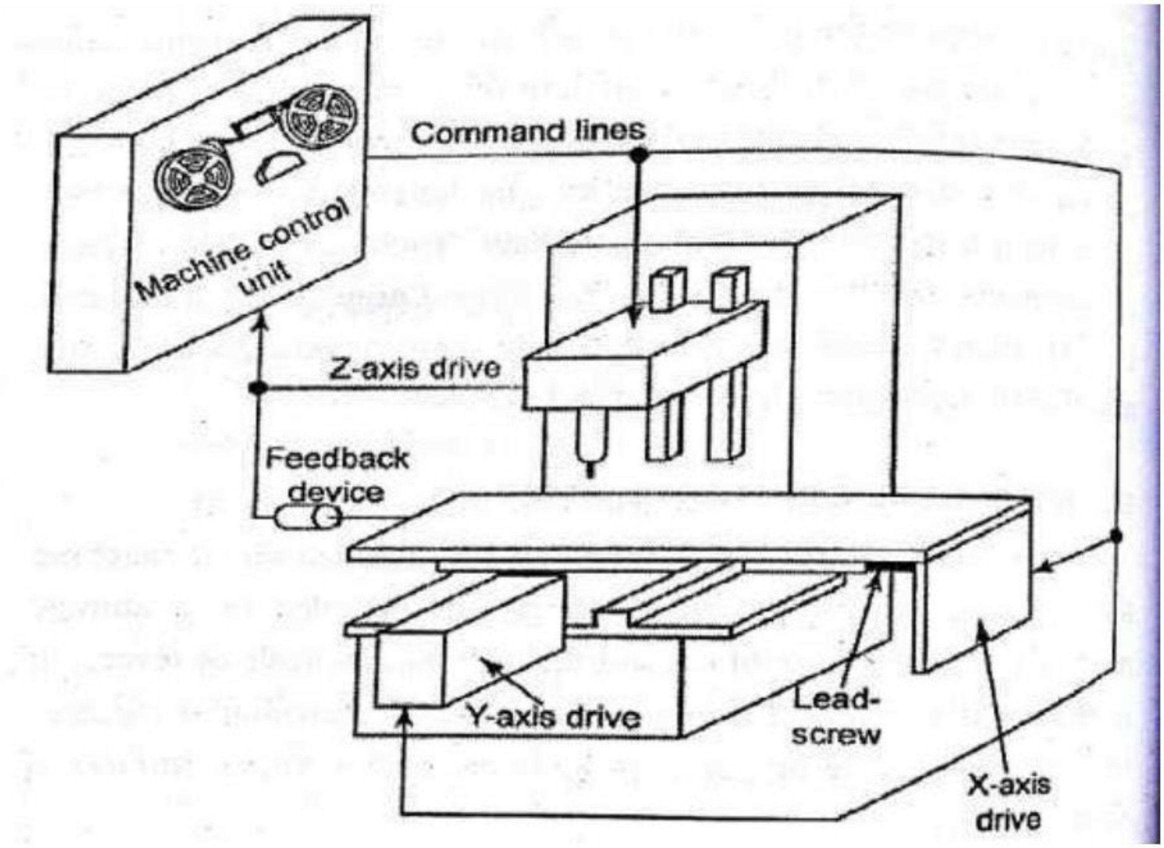
UNIT IV
FUNDAMENTAL OF CNC AND PART PROGRAMING

Definition of NC System:

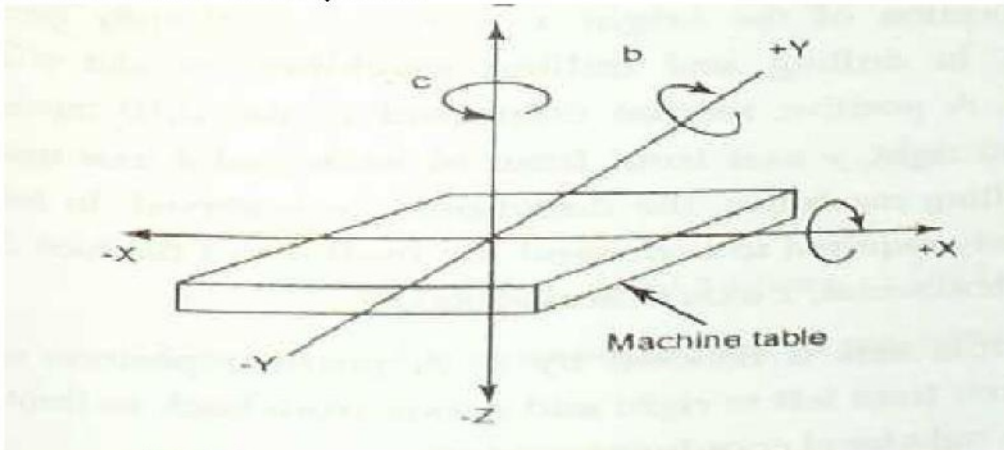
– A system in which actions are controlled by the direct insertion of numerical data at some point is known as NC system.

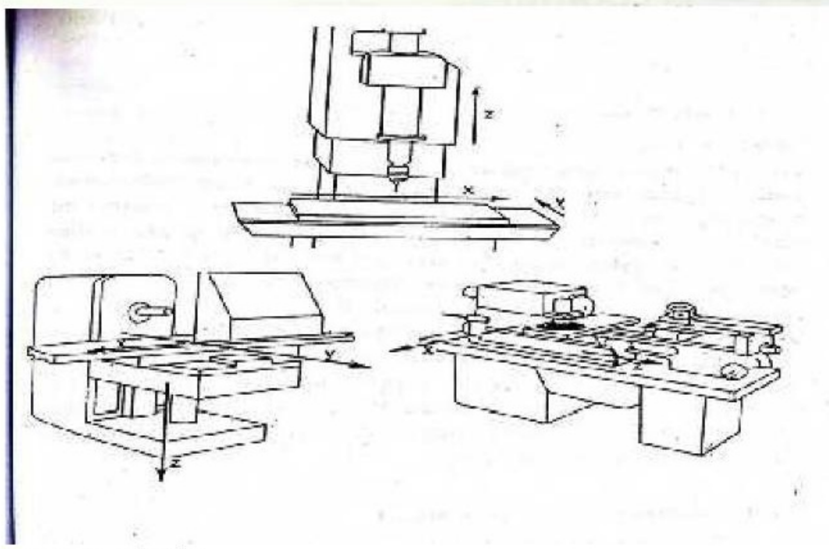


TYPES OF NC SYSTEM:

- Traditional numerical control (NC)
- Computer numerical control (CNC)
- Distributed numerical control (DNC)

Controlled axes in NC systems:

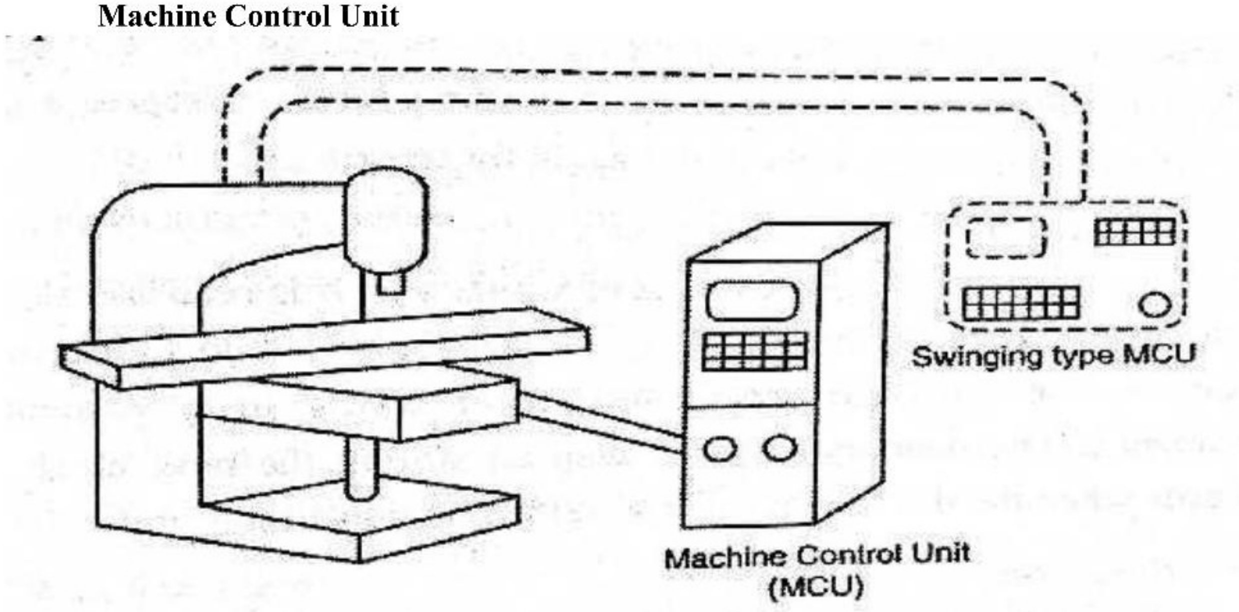




Basic components of NC:

- Software
- Machine Control Unit (MCU)
- Machine tool

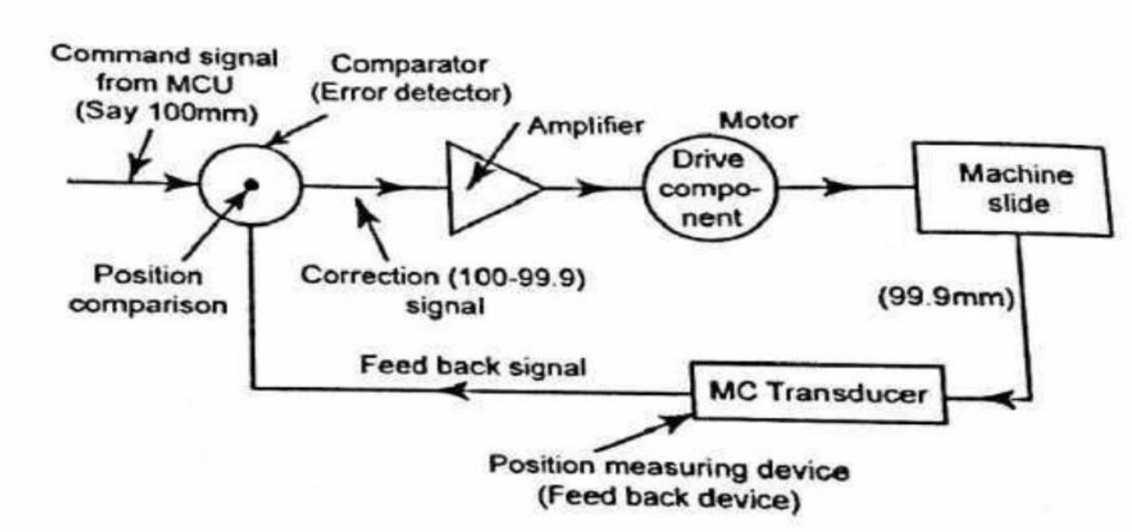
Machine Control Unit



CLASSIFICATION NC MACHINES BASED ON CONTROL SYSTEM

- Open- loop system in NC machines
- Closed loop system in NC machines

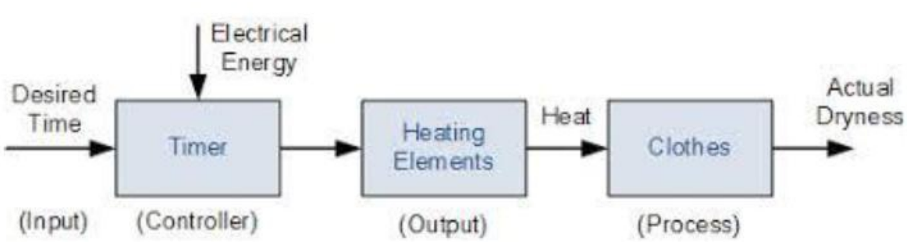
Open- loop system in NC machines



Closed-loop systems are designed to automatically achieve and maintain the desired output condition by comparing it with the actual condition. It does this by generating an error signal which is the difference between the output and the reference input. In other words, a "closed-loop system" is a fully automatic control system in which its control action being dependent on the output in some way
. The quantity of the output being measured is called the "feedback signal", and the type of control system which uses feedback signals to both control and adjust itself is called a CLOSED system

Open type of control system

OPen type of control system in which the output has no influence or effect on the control action of the input signal is called an Open-loop system. An "open-loop system" is defined by the fact that the output signal or condition is neither measured nor "fed back" for comparison with the input signal or system set point.



Various types of motion control system

In order to accomplish the machining process, the cutting tool and workpiece must be moved relative to each other. In NC, there are three basic types of motion control systems: -

Point-to-point

- Straight cut
- Contouring

Point-to-point NC

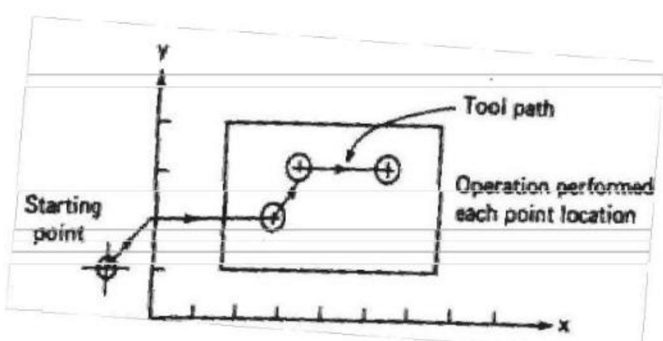
Point-to-point (PTP) is also sometimes called a positioning system. In PTP, the objective of the machine tool control system is to move the cutting tool to a predefined location. The speed or path by which this movement is accomplished is not import in point-to-point NC. Once the tool reaches the desired location, the machining operation is performed at that position.

NC drill presses are a good example of PTP systems. The spindle must first be positioned at a particular location on the work piece. This is done under PTP control. Then the drilling of the hole is performed at the location, and so forth. Since no cutting is performed between holes, there is no need for controlling the relative motion of the tool and work piece between hole locations. Figure illustrates the point-to-point type of control.

Positioning systems are the simplest machine tool control systems and are therefore the least expensive of the three types. However, for certain processes, such as drilling operations and spot welding, PIP is perfectly suited to the task and any higher level of control would be unnecessary.

Straight-cut NC

Straight-cut control systems are capable of moving the cutting tool parallel to one of the major axes at a controlled rate suitable for machinin to fabricate workpieces of rectangular configurations. With this type of NC system it is not possible to combine movements in more than a Single axis direction. Therefore, angular cuts on the workpiece would not be possible. An example of a straight-cut operation is shown in Figure



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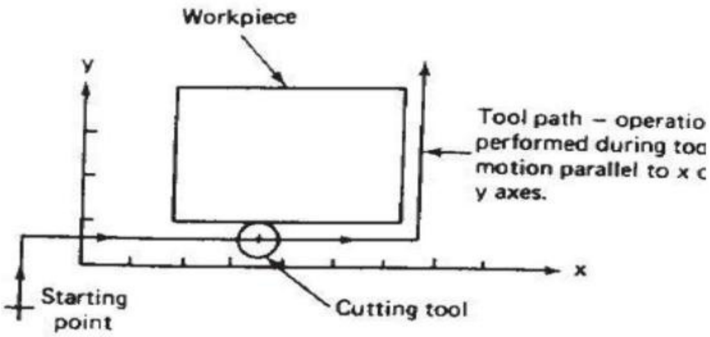
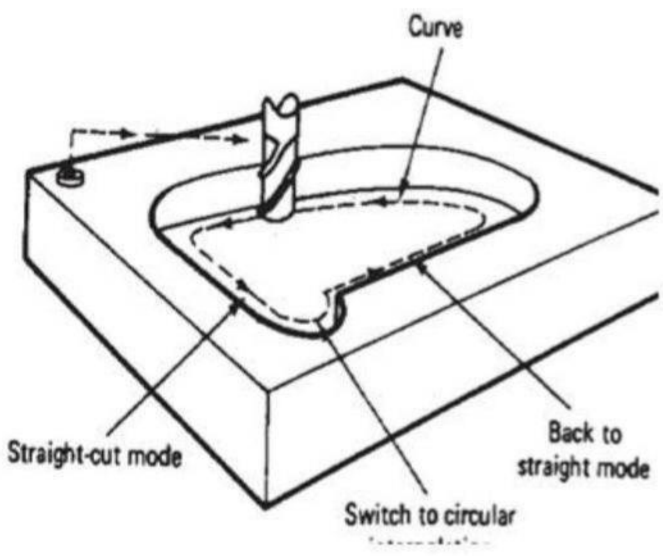
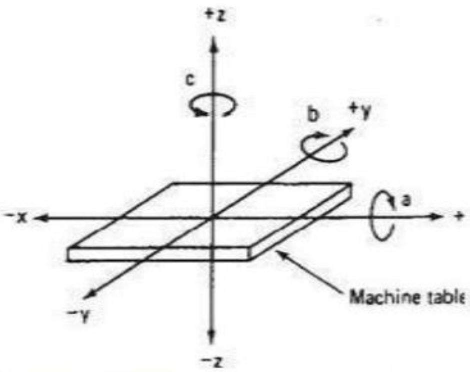


Contouring NC

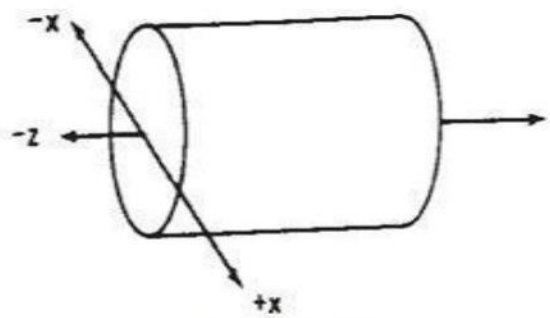
Contouring is the most complex, the most flexible, and the most expensive type of machine tool control. It is capable of performing both PTP and straight-cut operations. In addition, the distinguishing feature of contouring NC systems is their capacity for simultaneous control of more than one axis movement of the machine tool. The path of the cutter is continuously controlled to generate the desired geometry of the work piece. For this reason, contouring systems are also called continuous-path NC systems.



NC COORDINATE SYSTEMS



MILLING, DRILLING



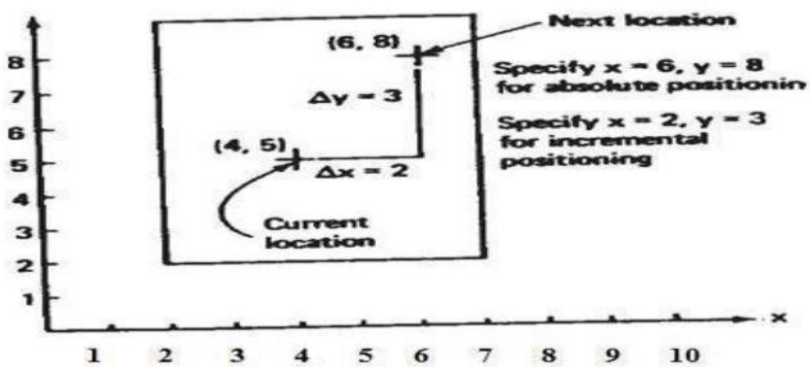
TURNING

The programmer must determine the position of the tool relative to the origin (zero point) of the coordinate system. NC machines have either of two methods for specifying the zero point. The first possibility is for the machine to have a fixed zero. In this case, the origin is always located at the same position on the machine. Usually, that position is the southwest comer (lower left-hand comer) of the table and all tool locations will be defined by positive x and y coordinates.

The second and more common feature on modern NC machines allows the machine operator to set the zero point at any position on the machine table. This feature is called **floating zero**. The part programmer is the one who decides where the zero point should be located. The decision is based on part programming convenience. For example, the work part may be symmetrical and the zero point should be established at the center of symmetry.

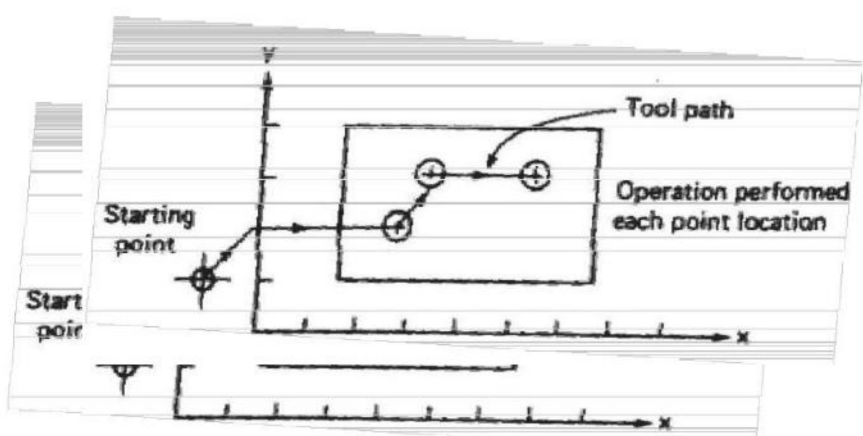
Another option sometimes available to the part programmer is to use either an absolute system of tool positioning or an incremental system. Absolute positioning means that the tool locations are always defined in relation to the zero point. If a hole is to be drilled at a spot that is 8 in. above the x axis and 6in. to the right of the y axis, the coordinate location of the bole would be specified as x = +6.OOO and y = +8.OOO. By contrast, incremental positioning means that the next tool location must be defined with reference to the previous tool location. If in our drilling example, suppose that the previous hole had been drilled at an absolute position of x = +4.OOO and y=+5.OOO. Accordingly, the incremental position instructions would be specified as x = +2.OOO and y= +3.OOO in order to move the drill to the desired spot. Figure illustrates the difference between absolute and incremental positioning.

Absolute versus incremental positioning



. Give an brief notes on Straight-cutNC

Straight-cut control systems are capable of moving the cutting tool parallel to one of the major axes at a controlled rate suitable for machining. It is therefore appropriate for performing



NC procedure

To utilize numerical control in manufacturing, the following steps must be accomplished.

Process Planning: The engineering drawing of the workpart must be interpreted in terms of the manufacturing processes to be used. this step is referred to as process planning and it is concerned with the preparation of a route sheet. The route sheet is a listing of the sequence of operations which must be performed on the work part. It is called a route sheet because it also lists the machines through which the part must be routed in order to accomplish the sequence of operations. We assume that some of the operations will be performed on one or more NC machines.

Part programming: A part programmer plans the process for the portions of the job to be accomplished by NC. Part programmers are knowledgeable about the machining process and they have been trained to program for numerical control. They are responsible for planning the sequence of machining steps to be performed by NC and to document these in a special format. There are two ways to program for NC.

Manual part programming

In manual programming, the machining instructions are prepared on a form called a part program manuscript. The manuscript is a listing of the relative cutter/work piece positions which must be followed to machine the part. In computer-assisted part programming, much of the tedious computational work required in manual part programming is transferred to the computer. This is especially appropriate for complex work piece geometries and jobs with many machining steps. Use of the computer in these situations results in significant savings in part programming time.

2. Answer in brief about Fixed zero and floating zero:

The programmer must determine the position of the tool relative to the origin (zero point) of the coordinate system. NC machines have either of two methods for specifying the zero point. The first possibility is for the machine to have a fixed zero. In this case, the origin is always located at the same position on the machine. Usually, that position is the southwest comer (lower left-hand comer)of the table and all tool locations will be defined by positive x and y coordinates.

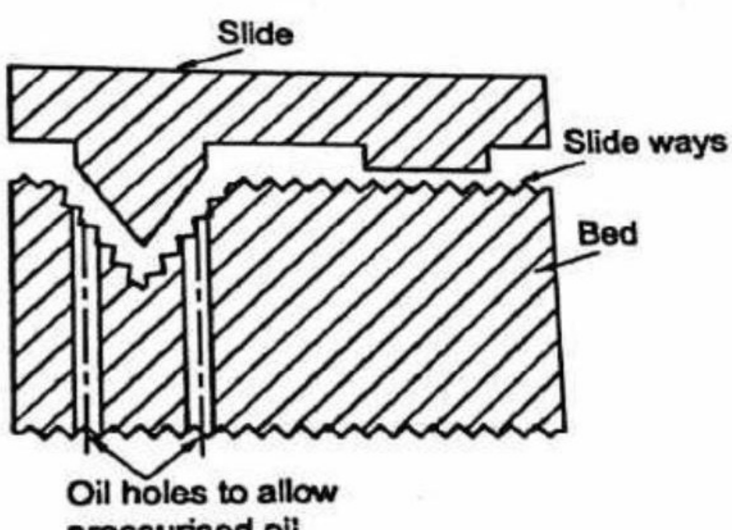
The second and more common feature on modern NC machines allows the machine operator to set the zero point at any position on the machine table. This feature is called floating zero. The part programmer is the one

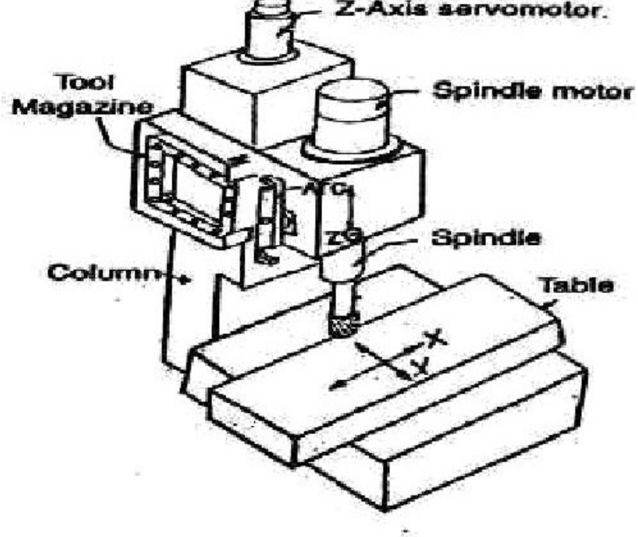
who decides where the zero point should be located. The decision is based on part programming convenience. For example, the work part may be symmetrical and the zero point should be established at the center of symmetry type of CNC used in these above- said fields are given below

- CNC lathes
- CNC turning centres
- Gear hobbing machines
- Gear shaping machines
- Tube bending
- Electron beam welding
- Press brakes
- Abrasive water jet machines
- Coordinate measuring machines

Special features of CNC machines

- CNC drive systems
- Feed drive
- Slide movement element
- coolant control
- Working of automatic tool changer
- Work holding system
- CNC controller
- Type of CNC machines





MACHINING CENTRES

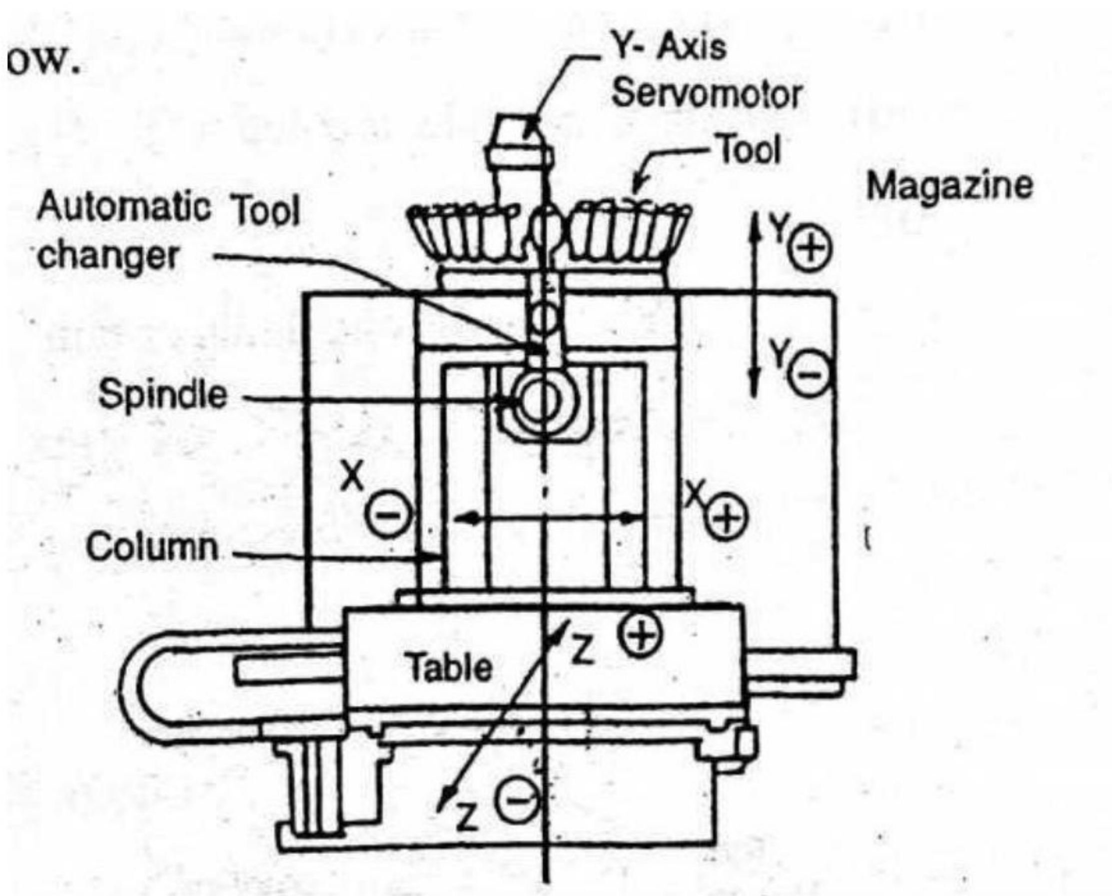
The following operations are carried out

- Milling
- Drilling
- Reaming
- Boring
- Tapping

Classification of machining centres

Horizontal spindle machining centres

Vertical spindle machining centre



APPLICATION OF CNC MACHINES:

– Metal cutting industry for processes

– In addition to metal cutting machines, CNC has also been applied to the following

  – Press working machine tools

  – Welding machines

  – Inspection machines

  – Assembly machines

  – Industrial robots

  – Cloth cutting

ADVANTAGES OF CNC MACHINES

– It increases in capacity for storing large part programs

– It increases the memory for part programme processing

– It is easy to edit the part programs on the control console

– CNC is more compatible

DISADVANTAGES OF CNC MACHINES

– Costly setup and skilled operators are required

– Computer programming knowledge is essential

– Maintenance is difficult

– Machines have to be installed in air conditioned places Part

program:

Elements of CNC machine tools: electric motors

1. Drives

Basic function of a CNC machine is to provide automatic and precise motion control to its elements such work table, tool spindle etc. Drives are used to provide such kinds of controlled motion to the elements of a CNC machine tool. A drive system consists of drive motors and ball lead-screws. The control unit sends the amplified control signals to actuate drive motors which in turn rotate the ball lead-screws to position the machine table or cause rotation of the spindle.

2. Power drives

Drives used in an automated system or in CNC system are of different types such as electrical, hydraulic or pneumatic.

- **Electrical drives**
  These are direct current (DC) or alternating current (AC) servo motors. They are small in size and are easy to control.
- **Hydraulic drives**
  These drives have large power to size ratio and provide stepless motion with great accuracy. But these are difficult to maintain and are bulky. Generally they employ petroleum based hydraulic oil which may have fire hazards at upper level of working temperatures. Also hydraulic elements need special treatment to protect them against corrosion.
- **Pneumatic drives**
  This drives use air as working medium which is available in abundant and is fire proof. They are simple in construction and are cheaper. However these drives generate low power, have less positioning accuracy and are noisy.

In CNC, usually AC, DC, servo and stepper electrical drives are used. The various drives used in CNC machines can be classified as:

a. Spindle drives to provide the main spindle power for cutting action
b. Feed drives to drive the axis

2.1 Spindle drive

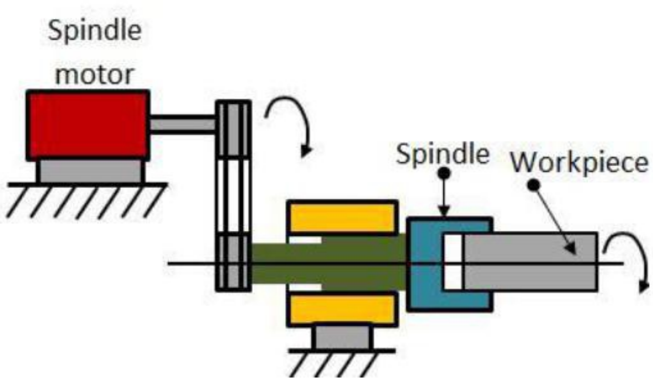


Fig. 4.1.1 Schematic of a spindle drive

The spindle drives are used to provide angular motion to the workpiece or a cutting tool. Figure 4.1.1 shows the components of a spindle drive. These drives are essentially required to maintain the speed accurately within a power band which will enable machining of a variety of materials with variations in material hardness. The speed ranges can be from 10 to 20,000 rpm. The machine tools mostly employ DC spindle drives. But as of late, the AC drives are preferred to DC drives due to the advent of microprocessor-based AC frequency inverter. High overload capacity is also needed for unintended overloads on the spindle due to an inappropriate feed. It is desirous to have a compact drive with highly smooth operation.

2.2 Feed Drives

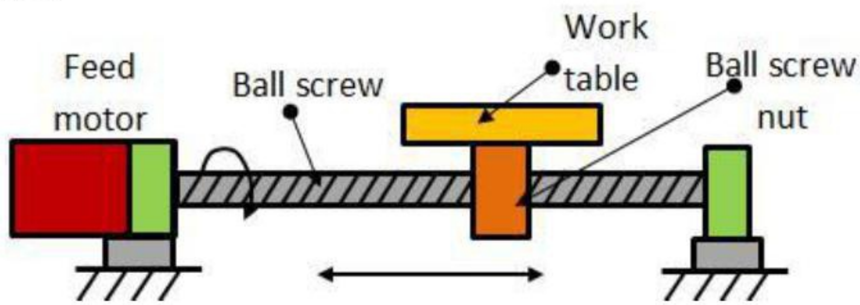


Fig. 4.1.2 Typical feed drive

These are used to drive the slide or a table. Figure 4.1.2 shows various elements of a feed drive. The requirements of an ideal feed drive are as follows.

- The feed motor needs to operate with constant torque characteristics to overcome friction and working forces.
- The drive speed should be extremely variable with a speed range of about 1: 20000, which means it should have a maximum speed of around 2000 rpm and at a minimum speed of 0.1 rpm.
- The feed motor must run smoothly.
- The drive should have extremely small positioning resolution.
- Other requirements include high torque to weight ratio, low rotor inertia and quick response in case of contouring operation where several feed drives have to work simultaneously.

Variable speed DC drives are used as feed drives in CNC machine tools. However now-a-days AC feed drives are being used.

STEPPER MOTOR

A STEPPER MOTOR also known as step motor or stepping motor, is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any position sensor for feedback (an open-loop controller), as long as the motor is carefully sized to the application in respect to torque and speed.

3. Electrical drives

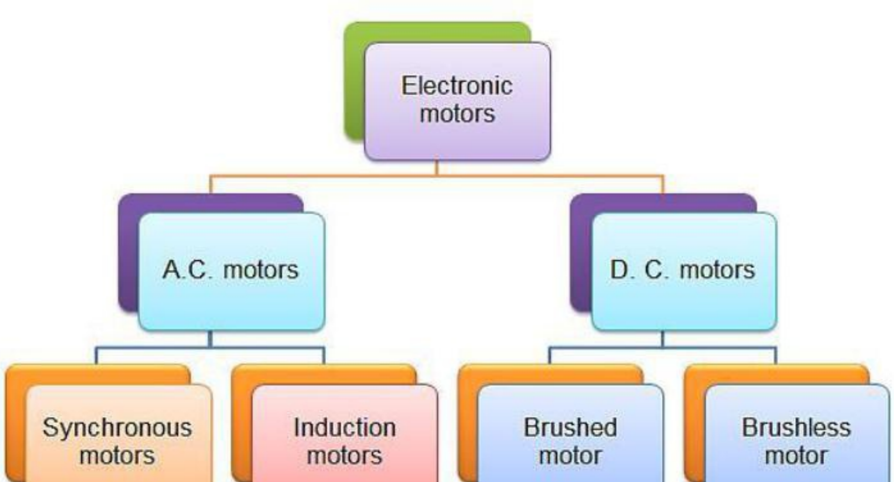


Fig. 4.1.3 Classification of motors

Electric drives are mostly used in position and speed control systems. The motors can be classified into two groups namely DC motors and AC motors (Fig. 4.1.3). In this session we shall study the operation, construction, advantages and limitations of DC and AC motors.

3.1. DC motors

A DC motor is a device that converts direct current (electrical energy) into rotation of an element (mechanical energy). These motors can further be classified into brushed DC motor and brushless DC motors.

3.1.1 Brush type DC motor

A typical brushed motor consists of an armature coil, slip rings divided into two parts, a pair of brushes and horse shoes electromagnet as shown in Fig. 4.1.4. A simple DC motor has two field poles namely a north pole and a south pole. The magnetic lines of force extend across the opening between the poles from north to south. The coil is wound around a soft iron core and is placed in between the magnet poles. These electromagnets receive electricity from an outside power source. The coil ends are connected to split rings. The carbon brushes are in contact with the split rings. The brushes are connected to a DC source. Here the split rings rotate with the coil while the brushes remain stationary

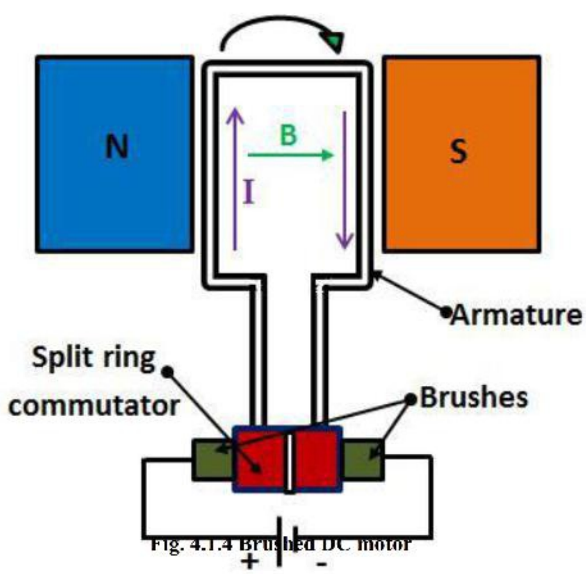


Fig. 4.1.4 Brushed DC motor

The working is based on the principle that when a current-carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by Fleming's left-hand rule. The magnitude of the force is given by

(4.1.1)

Where, B is magnetic field density in weber/m^2

I is the current in amperes and

L is the length of the conductor in meter

θ is the angle between the direction of the current in the conductor and the electric field

If the current and filed are perpendicular then θ=90°. The equation 4.1.1 becomes,

= (4.1.2)

A direct current in a set of windings creates a magnetic field. This field produces a force which turns the armature. This force is called torque. This torque will cause the armature to turn until its magnetic field is aligned with the external field. Once aligned the direction of the current in the windings on the armature reverses, thereby reversing the polarity of the rotor's electromagnetic field. A torque is once again exerted on the rotor, and it continues spinning. The change in direction of current is facilitated by the split ring commutator. The main purpose of the commutator is to overturn the direction of the electric current in the armature. The commutator also aids in the transmission of current between the armature and the power source. The brushes remain stationary, but they are in contact with the armature at the commutator, which rotates with the armature such that at every 180° of rotation, the current in the armature is reversed.

***Advantages of brushed DC motor*:**

- The design of the brushed DC motor is quite simple
- Controlling the speed of a Brush DC Motor is easy
- Very cost effective

***Disadvantages of brushed DC motor*:**

- High maintenance
- Performance decreases with dust particles
- Less reliable in control at lower speeds
- The brushes wear off with usage

3.1.2 <u>Brushless DC motor</u>

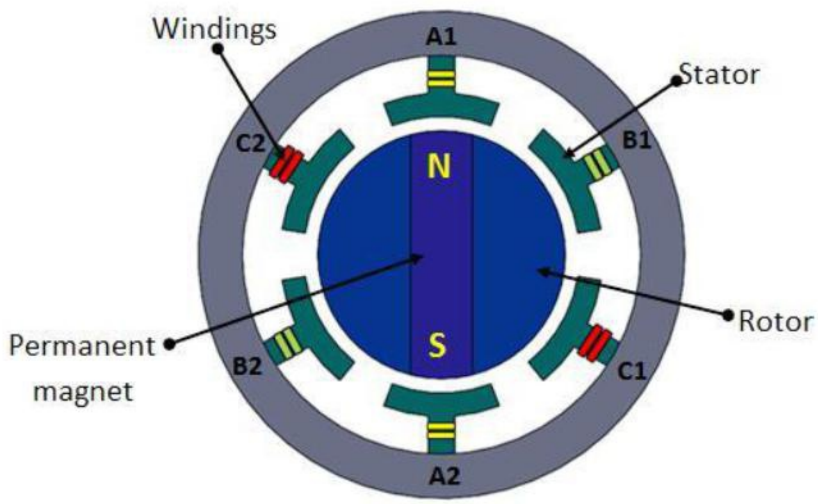


Fig. 4.1.5 Brushless DC motor

A brushless DC motor has a rotor with permanent magnets and a stator with windings. The rotor can be of ceramic permanent magnet type. The brushes and commutator are eliminated and the windings are connected to the control electronics. The control electronics replace the commutator and brushes and energize the stator sequentially. Here the conductor is fixed and the magnet moves (Fig. 4.1.5).

The current supplied to the stator is based on the position of rotor. It is switched in sequence using transistors. The position of the rotor is sensed by Hall effect sensors. Thus a continuous rotation is obtained.

***Advantages of brushless DC motor*:**
- More precise due to computer control
- More efficient
- No sparking due to absence of brushes
- Less electrical noise
- No brushes to wear out
- Electromagnets are situated on the stator hence easy to cool
- Motor can operate at speeds above 10,000 rpm under loaded and unloaded conditions
- Responsiveness and quick acceleration due to low rotor inertia

***Disadvantages of brushless DC motor*:**
- Higher initial cost
- Complex due to presence of computer controller
- Brushless DC motor also requires additional system wiring in order to power the electronic commutation circuitry

3.2 AC motors

AC motors convert AC current into the rotation of a mechanical element (mechanical energy). As in the case of DC motor, a current is passed through the coil, generating a torque on the coil. Typical components include a stator and a rotor. The armature of rotor is a magnet unlike DC motors and the stator is formed by electromagnets similar to DC motors. The main limitation of AC motors over DC motors is that speed is more difficult to control in AC motors. To overcome this limitation, AC motors are equipped with variable frequency drives but the improved speed control comes together with a reduced power quality.

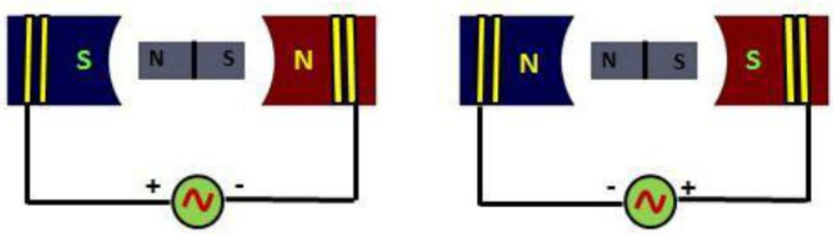


Fig. 4.1.6 AC motor working principle

The working principle of AC motor is shown in fig. 4.1.6. Consider the rotor to be a permanent magnet. Current flowing through conductors energizes the magnets and develops N and S poles. The strength of electromagnets depends on current. First half cycle current flows in one direction and in the second half cycle it flows in opposite direction. As AC voltage changes the poles alternate.

AC motors can be classified into synchronous motors and induction motors.

3.2.1 Synchronous motor

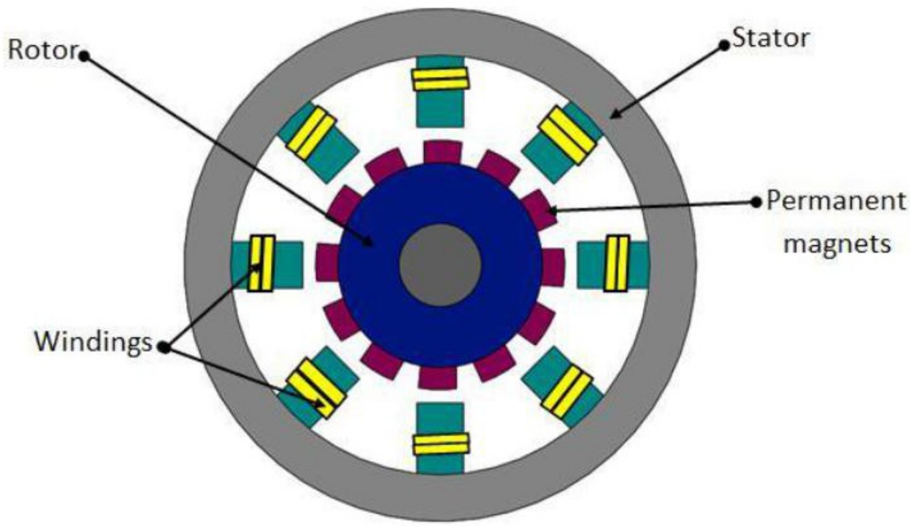
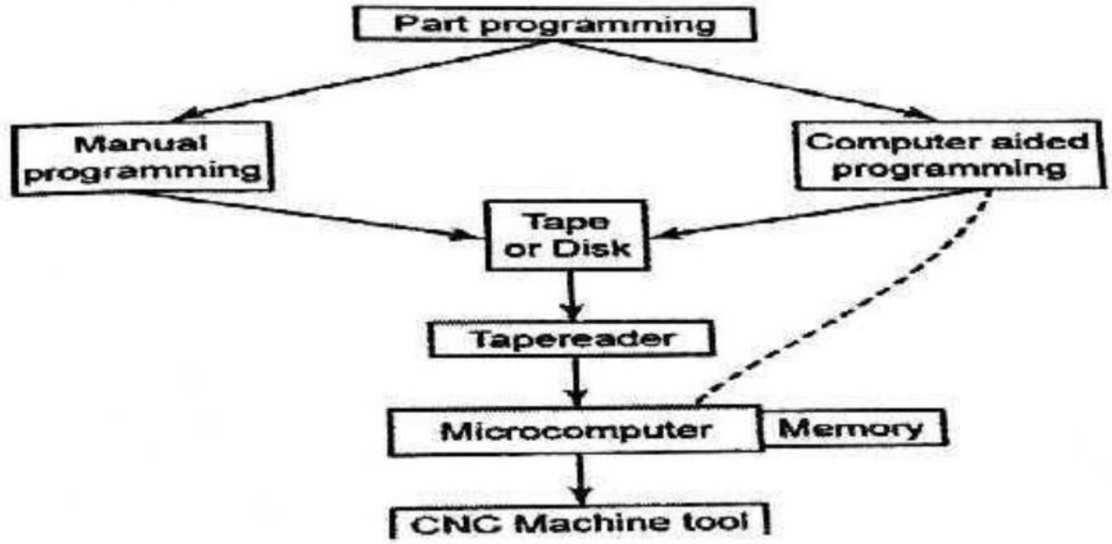


Fig. 4.1.7 Synchronous AC motor

A synchronous motor is an AC motor which runs at constant speed fixed by frequency of the system. It requires direct current (DC) for excitation and has low starting torque, and hence is suited for applications that start with a low load. It has two basic electrical parts namely stator and rotor as shown in fig. 4.1.7. The stator consists of a group of individual wounded electro-magnets arranged in such a way that they form a hollow cylinder. The stator produces a rotating magnetic field that is proportional to the frequency supplied. The rotor is the rotating electrical component. It also consists of a group of permanent magnets arranged around a cylinder, with the poles facing toward the stator poles. The rotor is mounted on the motor shaft. The main difference between the synchronous motor and the induction motor is that the rotor of the synchronous motor travels at the same speed as the rotating magnet.

The stator is given a three phase supply and as the polarity of the stator progressively change the magnetic field rotates, the rotor will follow and rotate with the magnetic field of the stator. If a synchronous motor loses lock with the line frequency it will stall. It cannot start by itself, hence has to be started by an auxiliary motor.

– The part programme is a set of instructions proposed to get the machined part starting with the desired blank and NC machine tool.



Methods of creating part programming:

- Manual part programming
- Computer assisted part programming (CAD/CAM)
- Manual data input
- Computer automated part programming

CNC MANUAL PART PROGRAMMING:

- To prepare a part programme using a manual method, the programmer writes the machining instructions on a special format called part programming manuscript.
- The manual programming jobs can be divided into two categories
  - Point to point jobs
  - Contouring jobs

DATA REQUIRED FOR PART PROGRAMMING

– Job dimensions/workpiece

– Work holding

– Feed/cutting speed

– Finished dimension with tolerance

– Sequence of operation

– Types of tools

5.18.6. Part Programme Format and Symbols

The programme format is N4/G2/X43/Y43/F03/S200/M03. From the above format, the following should be understood.

(i) N indicates the *block number* which has the number 1 to 9999.

(ii) G denotes the *preparatory function* having two digits 00 to 99.

(iii) X and Y co-ordinates may have up to seven digits each 1234567.

(iv) F indicates the *Feed* given.

(v) S indicates the speed of work (or) spindle.

(vi) M denotes miscellaneous functions.

(vii) Enter or end of the block (for each line it should be given).

– Mounting of tools

PREPARATORY FUNCTIONS (G) IN PART PROGRAMMING

– Preparatory commands which prepare the machine or tool for different modes of movement positioning.

Function codes	***Meaning***
G00	Point to point positioning
G01	Linear interpolation
G02	Circular interpolation, clockwise
G03	Circular interpolation, anticlockwise
G04	Dwell
G06	Parabolic interpolation
G08	Acceleration
G09	Deceleration
G17	XY plane selection
G18	XZ plane selection
G19	YZ plane selection
G25, G29	Unassigned
G33	Tread cutting, constant lead
G34	Tread cutting, increasing lead
G35	Tread cutting, decreasing lead
G36, G39	Unassigned
G40	Tool offset cancel

G41 G42	Tool offset
G54, G59	Linear shift
G60	Fine positioning
G61	Medium positioning
G62	Coarse positioning (fast)
G63	Tapping
G70	Inch programming
G71	Metric (mm)
G80	Canned cycle cancel
G81, G89	Canned cycles
G90	Absolute dimension
G91	Incremental dimension
G92	Position pre-set
G93	Inverse time, feed rate
G94	Feed/minute
G95	Feed/revolution
G96	Constant surface speed
G97	Spindle speed

MISCELLANEOUS FUNCTION IN PART PROGRAMMING

– The function not relating the dimensional movement of the machine but it denotes the auxiliary or switching information is called miscellaneous functions.

– For example coolant on/off, spindle speed

Function codes	*Meaning*
M00	Programmed stop
M01	Optional stop
M02	End of programmewithout skip back
M03	Spindle clockwise
M04	Spindle anticlockwise
M05	Spindle stop
M06	Tool change
M07	high pressure coolant ON
M08	Low pressure coolant ON
M09	Coolant OFF
M10	Clamp workpiece
M11	Release workpiece
M12	Hydraulic power rotary table ON
M13	Last replacement tool
M14	Oil hole frill coolant ON
M16	Heavy tool change
M17	Tap cycle confirmation
M18	Tap cycle cancel
M19	Spindle orientation
M20	Coolant nozzle up
M21	Coolant nozzle middle
M22	Coolant nozzle down
M23	Detection of contact in – X
M24	Detection of contact in +X
M25	Detection of contact in –Y
M26	Detection of contact in +Y
M27	Tool breakage detection
M28	Quill forward
M29	Quill back
M30	End of programme with skip back
M31	Delete block 'off'
M35	Transition taper ON while threading
M36	Transition taper ON while threading
M40	Transmission stage I

INTERPOLATION IN PART PROGRAMMING

– It is the process of developing coordinate points in between start and finish coordinates.

– Interpolation in NC machining is required to calculate the intermediate points of a curve or straight line when its start and end coordinates are given. Interpolation may be linear, circular or cubic/parabolic.

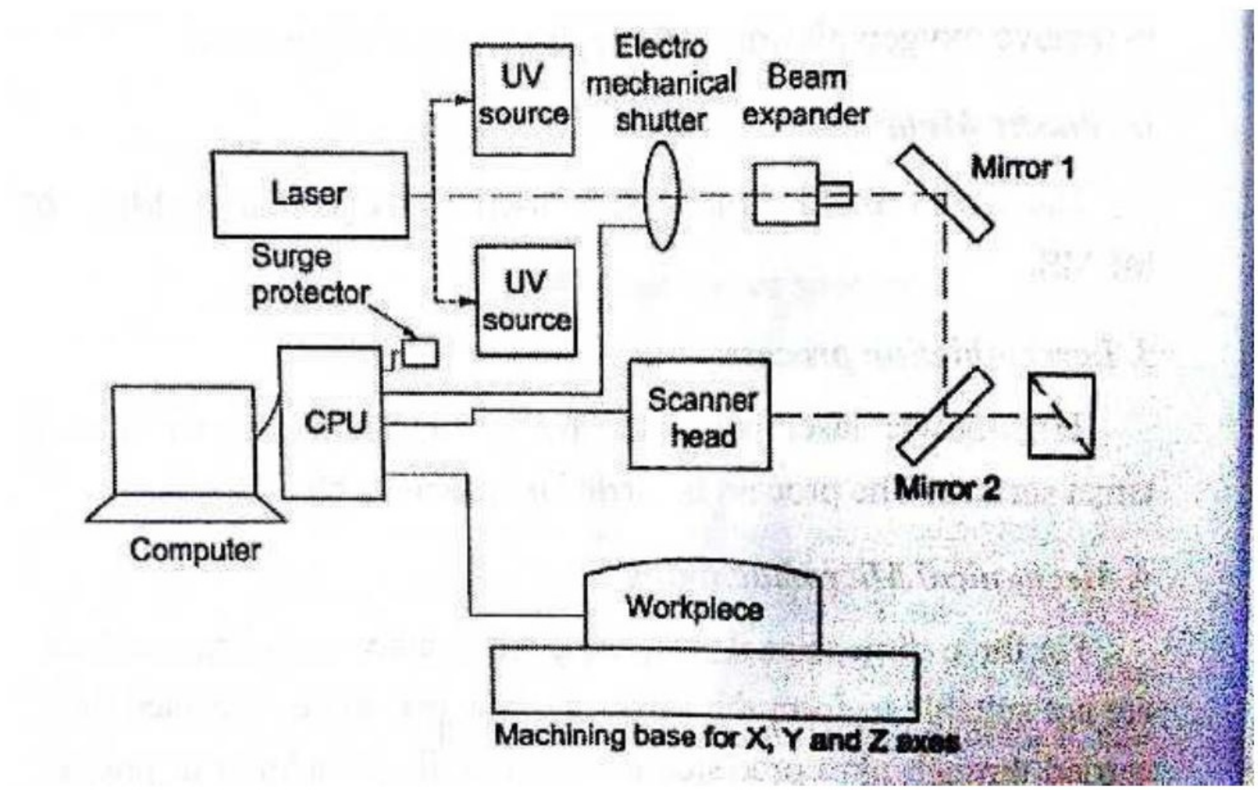
MICROMACHINING

– Micromachining refers of the technique for the fabrication of 3D structure on the micrometer scale. Micromachining refers the super finishing, a metalworking process for producing very fine surface finishes.

– The various types of micromachining process are given below

  – Bulk micromachining

  – Surface micromachining



SURFACE MICROMACHINING

– In surface machining process, the structures are created on top of a substrate. In this case, a silicon substrate (wafer) is selectively etched to produce structures.

– In this machining the microstructures are built by deposition and etching of different structural layers on top of the substrate.

WAFER MACHINING